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Les documents ci-joints sont conformes aux pièces originales relative à la demande de brevet spécifiée aux pages suivantes, déposées auprès de l'Office soussigné, en tant qu'Office récepteur au sens de l'article 10 du Traité de coopération en matière de brevets (PCT).

Confirmation

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Patentverfahren
Administration des brevets
Patent Administration   Rolf Hofstetter

PCT REQUEST

13-19.B.WO-P

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0	For receiving Office use only	
0-1	International Application No.	**PCT/CH 02 / 00 4 8 0**
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0-3	Name of receiving Office and "PCT International Application"	**RO / CH - Internationale Anmeldung PCT**

0-4	Form - PCT/RO/101 PCT Request	
0-4-1	Prepared using	**PCT-EASY Version 2.92 (updated 01.06.2002)**
0-5	Petition The undersigned requests that the present International application be processed according to the Patent Cooperation Treaty	
0-6	Receiving Office (specified by the applicant)	**Swiss Federal Intellectual Property Institute (RO/CH)**
0-7	Applicant's or agent's file reference	**13-19.B.WO-P**
I	Title of invention	**DIAMAGNETIC LEVITATION**
II	Applicant	
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PCT REQUEST

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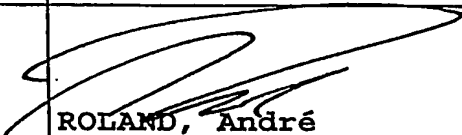
V	Designation of States	
V-1	Regional Patent (other kinds of protection or treatment, If any, are specified between parentheses after the designation(s) concerned)	AP: GH GM KE LS MW MZ SD SL SZ TZ UG ZM ZW and any other State which is a Contracting State of the Harare Protocol and of the PCT EA: AM AZ BY KG KZ MD RU TJ TM and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT EP: AT BE BG CH&LI CY CZ DE DK EE ES FI FR GB GR IE IT LU MC NL PT SE SK TR and any other State which is a Contracting State of the European Patent Convention and of the PCT OA: BF BJ CF CG CI CM GA GN GQ GW ML MR NE SN TD TG and any other State which is a member State of OAPI and a Contracting State of the PCT
V-2	National Patent (other kinds of protection or treatment, if any, are specified between parentheses after the designation(s) concerned)	AE AG AL AM AT AU AZ BA BB BG BR BY BZ CA CH&LI CN CO CR CU CZ DE DK DM DZ EC EE ES FI GB GD GE GH GM HR HU ID IL IN IS JP KE KG KP KR KZ LC LK LR LS LT LU LV MA MD MG MK MN MW MX MZ NO NZ OM PH PL PT RO RU SD SE SG SI SK SL TJ TM TN TR TT TZ UA UG US UZ VC VN YU ZA ZM ZW
V-5	Precautionary Designation Statement In addition to the designations made under items V-1, V-2 and V-3, the applicant also makes under Rule 4.9(b) all designations which would be permitted under the PCT except any designation(s) of the State(s) indicated under item V-6 below. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit.	
V-6	Exclusion(s) from precautionary designations	NONE
VI	Priority claim	NONE
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VIII	Declarations	Number of declarations	
VIII-1	Declaration as to the identity of the inventor	–	
VIII-2	Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent	–	
VIII-3	Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application	–	
VIII-4	Declaration of inventorship (only for the purposes of the designation of the United States of America)	–	
VIII-5	Declaration as to non-prejudicial disclosures or exceptions to lack of novelty	–	
IX	Check list	number of sheets	electronic file(s) attached
IX-1	Request (including declaration sheets)	5	–
IX-2	Description	7	–
IX-3	Claims	1	–
IX-4	Abstract	1	EZABST00.TXT
IX-5	Drawings	4	–
IX-7	TOTAL	18	
	Accompanying items	paper document(s) attached	electronic file(s) attached
IX-8	Fee calculation sheet	✓	–
IX-17	PCT-EASY diskette	–	Diskette
IX-19	Figure of the drawings which should accompany the abstract	1	
IX-20	Language of filing of the international application	English	
X-1	Signature of applicant, agent or common representative		
X-1-1	Name (LAST, First)	ROLAND, André	

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10-1	Date of actual receipt of the purported international application	0 2. Sep. 2002 (0 2. 09. 02)
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10-2-1	Received	
10-2-2	~~Not received~~	
10-3	Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application	
10-4	Date of timely receipt of the required corrections under PCT Article 11(2)	
10-5	International Searching Authority	ISA/EP
10-6	Transmittal of search copy delayed until search fee is paid	

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11-1	Date of receipt of the record copy by the International Bureau	

Patent documents:

3,831,287 USA 1974 G01C 9/00
5,396,136 USA 1995 H02K 7/09

Other publications:

R. Moser, J. Sandtner, H. Bleuler, Diamagnetic Suspension System for Small Rotors, Journal of Micromechatronics, Vol.1, N°2, 2001.

R. Moser, J. Sandtner, H. Bleuler, Diamagnetic Suspension Assisted by Active Electrostatic Actuators, 6th International Symposium on Magnetic Suspension Technology, October 6th 2001.

R. Moser, Y-J. Regamey, H. Bleuler, Passive Diamagnetic Levitation for Flywheels, ISMB, September 24th 2002.

R. Moser, F. Barrot, H. Bleuler, Optimization of Two-Dimensionnal Permanent Magnet Arrays for Diamagnetic Levitation, MAGLEV, September 9th 2002.

Science Toys, Levitating Pyrolitic Graphite:
http://www.scitoys.com/scitoys/scitoys/magnets /pyrolitic graphite.html
July 2002.

Abstract/Introduction

The present invention relates to the optimization of the two-dimensional permanent magnet arrays used for diamagnetic levitation and to the high sensitivity measuring devices, based on the magnetic levitation of a diamagnetic body over these 2D permanent magnets array.

Prior Art

In the US patent 5,396,136 an array of permanent magnets (Opposite 2D) is levitated by magnetic interaction with a diamagnetic material. As we will see in next section, this is not the most optimized 2D arrangement of permanent magnets.
In the US patent 3,831,287 a tiltmeter is designed using diamagentic levitation but without axial contact-less stabilization. We will see that in our implementation of a diamagnetic tilmeter the diamagnetic levitation is axially controled to produce an absolutly contact-less levitation.

Description of the present invention

Optimisation of the diamagnetic levitation:

See the description in the attached article (*Optimization of two-dimensionnal permanent magnet arrays for diamagnetic levitation*). We found that the array of permanent magnets that we call "Halbach 2D" gives the greatest levitation force.

Implementation in precision instrumentation:

Several kinds of precision intruments can be designed on the principle of a diamagnetic material

levitated over a 2D array of permanent magnets.

We will describe a prefered embodiment (cf Fig I, II, III) that can be used as an acceleration sensor, a tiltmeter, a gyroscope (with the addition of an alternating voltage applied on comb electrodes instead of the plain electrodes).

With the adjunction of a compenseting magnet (as described in *"Passive Diamagnetic Levitation for Flywheels"* and *Optimization of Two-Dimensionnal Permanent Magnet Arrays for Diamagnetic Levitation*) the bigger body can be diamagnetically levitated and other aparitus such as flywheel can be designed.

In the prefered embodiment described in Fig I,

A diamagnetic disc surrounded with an aluminum crown is levitated over a Halbach-2D array of permanent magnet. The position of the disc is controled in a feed-back loop which is made of a 4 segments optical sensor (spoted by an infrared LED through the diamagnetic disc) and a controler (Fig II and III) that generates the required voltage to ' 2 pairs electrodes in order to maintain (thanks to the generaated electrostatic forces) the diamagnetic disc when it is subjected to motion (due to shaking in case of a seismic sensor, or due to angular displacement in case of an X-Y tiltmeter). The diamagnetic mass is held at a predefined position with a feedback loop:

for instance in the case of the seismometer application, the forces generated for the control are proportionnal to the soil accelerations

As we can see in Fig. IV the measurements with the 4 segments optical sensor are differential.

Of course we can also use 2 pairs of proximity sensors facing each others around the aluminum disc and we would also have a differential measurement (the measurement becomes independant of temperature)

Advantage of the present invention

The differential measurements and the absence of contact allows hight accuracy measurements

Passive (no energy consumption) frictionless levitation of a mass that can be used (with the same basic embodiment/implementation) in various high precision and small measurement instruments made of low cost components.

Applications

Seismic sensor, bi directional (X, Y) inclinometer, gyroscope, X-Y tables for precise measurements.

Optimization of two-dimensional permanent magnet arrays for diamagnetic levitation

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Keywords

Contact-less levitation, Diamagnetism, Magnetic bearings, Permanent magnets, Pyrolytic graphite

Abstract

This paper presents new results in the field of passive diamagnetic levitation of macroscopic objects. Two dimensional permanent magnet arrays have been analyzed and optimized in order to obtain high thrust force and stiffness for fully passive magnetic levitation at room temperature in all 6 degrees of freedom. Experimental results with strongly diamagnetic materials like pyrolytic graphite indicate that diamagnetic levitation can be an interesting alternative to active magnetic bearings. Possible applications are pointed out and functional experimental prototypes are presented.

1 Introduction

Novel results for the optimization of fully contact-free passive suspension of objects at room temperature are presented. Earnshaws' theorem [1] discards the possibility of passive static magnetic levitation, but by taking advantage of the diamagnetic effect, passive magnetic systems can be stabilized. A diamagnetic material for levitation purposes was already proposed [2], the pyrolytic graphite, and full suspension and asynchronous propulsion of small disc shaped rotors was presented in [3]. Also, one-dimensional magnet arrangements have been investigated and optimized by finite element simulation. [4]. In the present report we show that, by optimizing a 2 D permanent magnet array in two dimensions, the obtainable thrust force can be significantly increased, allowing the passive static levitation without weight compensation of objects weighting up to several grams.

2 Passive Diamagnetic Levitation

2.1 Principle

In diamagnetic materials, the presence of an external field induces a slight net magnetic moment, an effect akin to electronic polarization in dielectric materials. This induced magnetic moment translates into a slightly negative magnetic susceptibility and therefore into a relative permeability slightly less than unity. If such a diamagnetic substance is placed in a non-uniform magnetic field, it is attracted to the regions where the field is weak. In other words, a diamagnetic substance is "repelled" by a non-uniform magnetic field. The amplitude of the repelling force is proportional to the cross product of the gradient and amplitude of the applied magnetic field. The highest diamagnetic effect can be observed at room temperature using NeFeB permanent magnets and highly orientated graphite (HOPG – highly orientated pyrolytic graphite).

For magnetic levitation, we propose the use of the less orientated, less pure and much cheaper pyrolithic graphite (PG).

2.2 Studied case of diamagnetic levitation

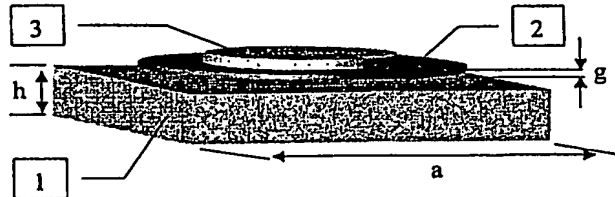Figure 1 depicts the studied case of passive diamagnetic levitation:

Fig. 1. Loaded pyrolytic graphite plate levitating with an air-gap g over a permanent magnet array of dimensions $a \times a \times h$.

A permanent magnet array 1 of square dimension a and height h lifts a plate of pyrolytic graphite 2 on which the payload 3 is located. This is a variant of diamagnetic levitation, the only known form of 'real' levitation at room temperature (without any energy input).

2.3 Variants of permanent magnet arrays

The magnet array of figure 1 can be decomposed into sub-magnets of different magnetization directions. Figure 2 shows the investigated arrangements and their nomenclature:
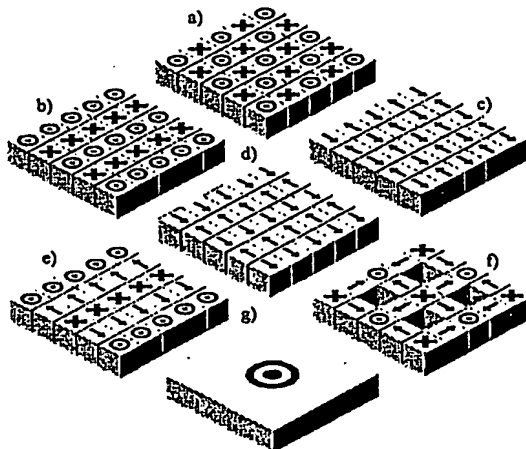
Fig. 2. Possible magnet arrays for diamagnetic levitation. a) Opposite 2D, b) Opposite 1D, c) Repulsive 2D, d) Repulsive 1D, e) Halbach 1D, f) Halbach 2D, g) Reference

The different arrangements are compared with a monolithic magnet (position 'g' in figure 2). By subdividing the available magnet volume into submagnets of different magnetization direction, the total magnetic flux and its gradient can be varied. Since the diamagnetic repulsion force is proportional to the flux' amplitude and gradient, the force should have a different allure in function of the air gap g for the various magnet arrangements.

3   Experimental Results

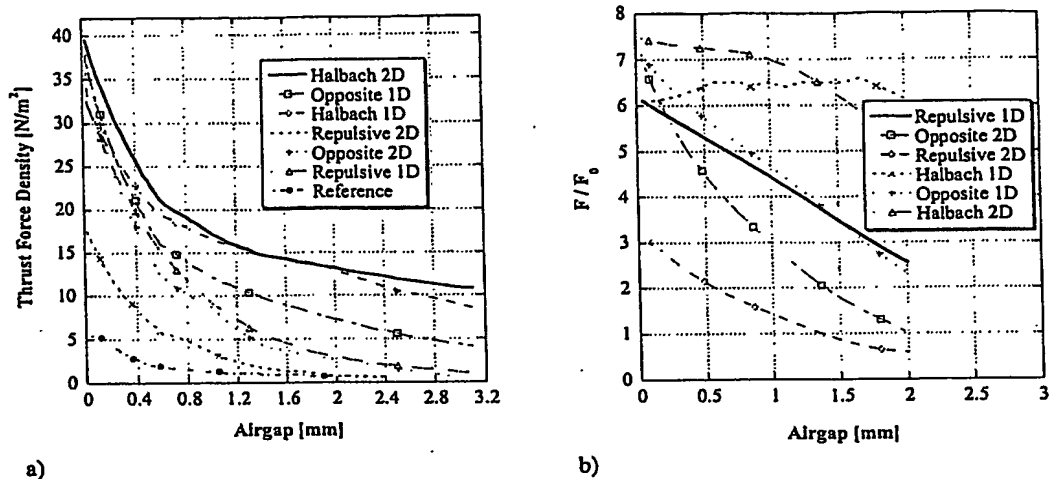Figure 3 plots the thrust force densities versus the air-gap g for the mentioned magnet arrangements:

Fig. 3. a) Thrust force density for various NeFeB magnet arrangements for h = 5mm. b) Array performance F, compared to a monolithic reference F_0. The pyrolytic graphite specimen has a thickness of 1 mm.

It can be seen (figure 3a) that for a 5mm thick magnet array, using a Halbach 2D arrangement, up to 40 N/m^2 force density can be obtained (if the rotor has a 1mm thick pyrolytic graphite layer). This force density allows already the passive suspension of objects weighing several grams. Using the Halbach 2D arrangement, the performance can be increased up to a factor eight with respect to the monolithic permanent magnet block. The other interesting magnet arrangements are the Halbach 1D, the Opposite 1D and 2D and Repulsive 1D. The Halbach 2D arrangements features by far the highest force density per submagnet (see figure 2). The Opposite 2D is the only magnet array that can be assembled without additional glue, which can be a decisive advantage.

4   Prototypes

4.1   Non-weight compensated levitation

Figure 3 suggests the possibility to levitate objects weighting several grams without weight compensation. Figure 4 shows the experimental verification, using a rotor weighting 3 grams.
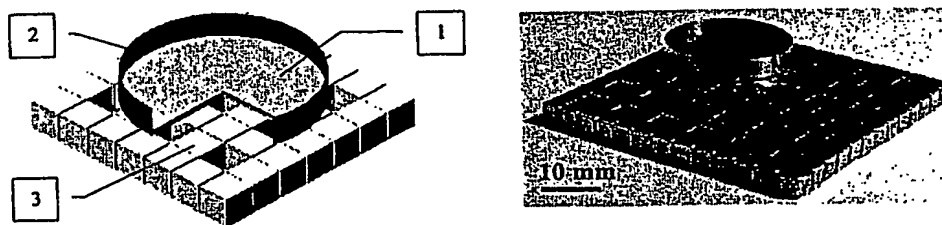
Fig. 4. Non-weight compensated diamagnetic levitation. a) Principle b) Photo of experimental verification

A disc shaped plate made out of pyrolytic graphite 1 and loaded with an aluminum ring 2 is levitating over a Halbach 2D array 3 (see figure 2f). The air-gap between rotor and magnet array is about 200µm. Obviously for stable levitation in the vertical axis, it would be enough if the magnet array has just the same dimensions as the rotor. We observed, using the experimental setup shown in figure 3, that for a certain ratio between rotor diameter and sub-magnet side length (the sub-magnets which form the magnet array are of cubic shape), passive stable levitation in five degrees of freedom is possible. Figure 5 sketches this situation:
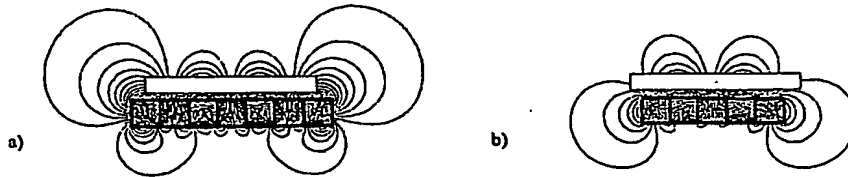
Fig. 5. a) Five degree of freedom levitation b) three degree of freedom levitation (unstable for horizontal translations). Flux-lines are simulated using the finite element method.

It can be seen that for miniaturized systems where the payload is in the order of some grams and contact-less levitation is required, diamagnetic actuators can be an interesting solution. Based on the measurements (figure 3), the following arrangements are proposed for various concrete applications:
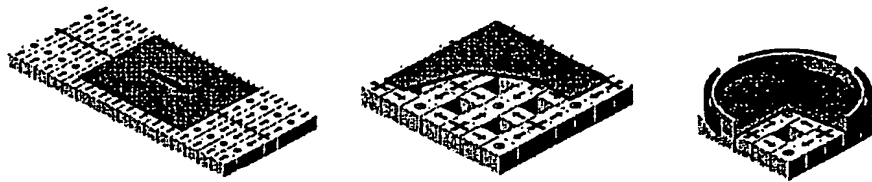
Fig. 6. a) Linear guide b) 6 DOF suspension c) Unstable contact-less suspension with active electrostatic actuators (acceleration sensing)

4.2   Weight compensated levitation

This diamagnetic levitation principle [4] is shown in figure 7:
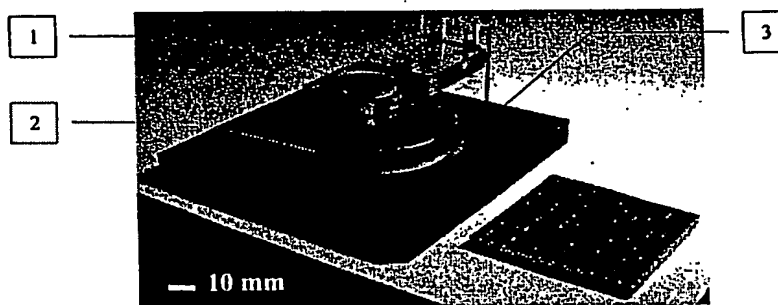

Fig. 7. Weight compensated diamagnetic levitation. Photo of experimental verification. Rotor weights 70 grams.

By adding a magnetic or ferromagnetic element on the rotor 2, the weight of the rotor is almost compensated using a permanent magnet 1. The remaining weight is compensated by the interaction between the pyrolytic graphite and the magnet array. Using a Halbach 2D array, a 5 mm thick magnet array was able to levitate a disc shaped rotor weighting 70 grams (10 mm thickness, 70 mm diameter). This compact passive and remarkably stable levitation device could find applications in the field of precise rotary positioning of optical devices [4].

5 Conclusion

Strong diamagnetic materials such as pyrolytic graphite are repelled by magnetic fields and therefore develop forces opposed to a magnet. Using strong rare earth magnets such as NeFeB, stable passive levitation of macroscopic objects at room temperature can be obtained. We determined the optimal permanent magnet pattern that supports a diamagnetic disc with respect to a maximization of the thrust force density. Using a Halbach array in two dimensions of 5 mm thickness, a 3 cm diameter disc weighting 3 grams could be stabilized 200μm above the magnet array. The trust force of such a Halbach array was shown to be 8 times higher than the thrust force of a monolithic magnet of same dimension.

Different applications were pointed out, such as a linear guide, a 6 degree of freedom suspension for rectangular plates, as well as a potential acceleration sensor, where the unstable horizontal degrees of freedom are controlled by active electrostatic actuators.

The compactness and simplicity of the presented levitation system (no active control, no sensors, no amplifiers and no control computer, no air compressors for air film, no low temperatures for superconductivity) without any kind of losses makes it an interesting solution for the levitation, positioning and guidance of objects weighting up to several grams.

6 Acknowledgments

7 References

1. Earnshaw S. *On the nature of the molecular forces which regulate the constitution of the lumiferous ether*, Trans. Camb. Phil. Soc, 1842, vol. 7, pp. 97-112.

2. Moser R., Bleuler H. *Precise Positioning Using Electrostatic Glass Motor with Diamagnetically Suspended Rotor*, IEEE Transactions on applied superconductivity, IN PRESS

3. Moser R., Sandtner J., Bleuler H. *Diamagnetic suspension system for small rotors*, Journal of Micromechatronics, VSB, Vol.1, No. 2, (2001), pp. 131-137.

4. Moser R., Sandtner J., Bleuler H., *Diamagnetic suspension assisted by active electrostatic actuators*, 6th International Symposium on Magnetic Suspension Technology, Turin 2001, pp. 241-246

5. Geim A.K., Simon M. D. *Magnet levitation at your fingertips*, Nature 400 (1999), pp. 323-324

Claim

1. Electrostatic feed-back control of a diamagnetic rotor levitated by a
    2D array of permanent magnets.

Abstract

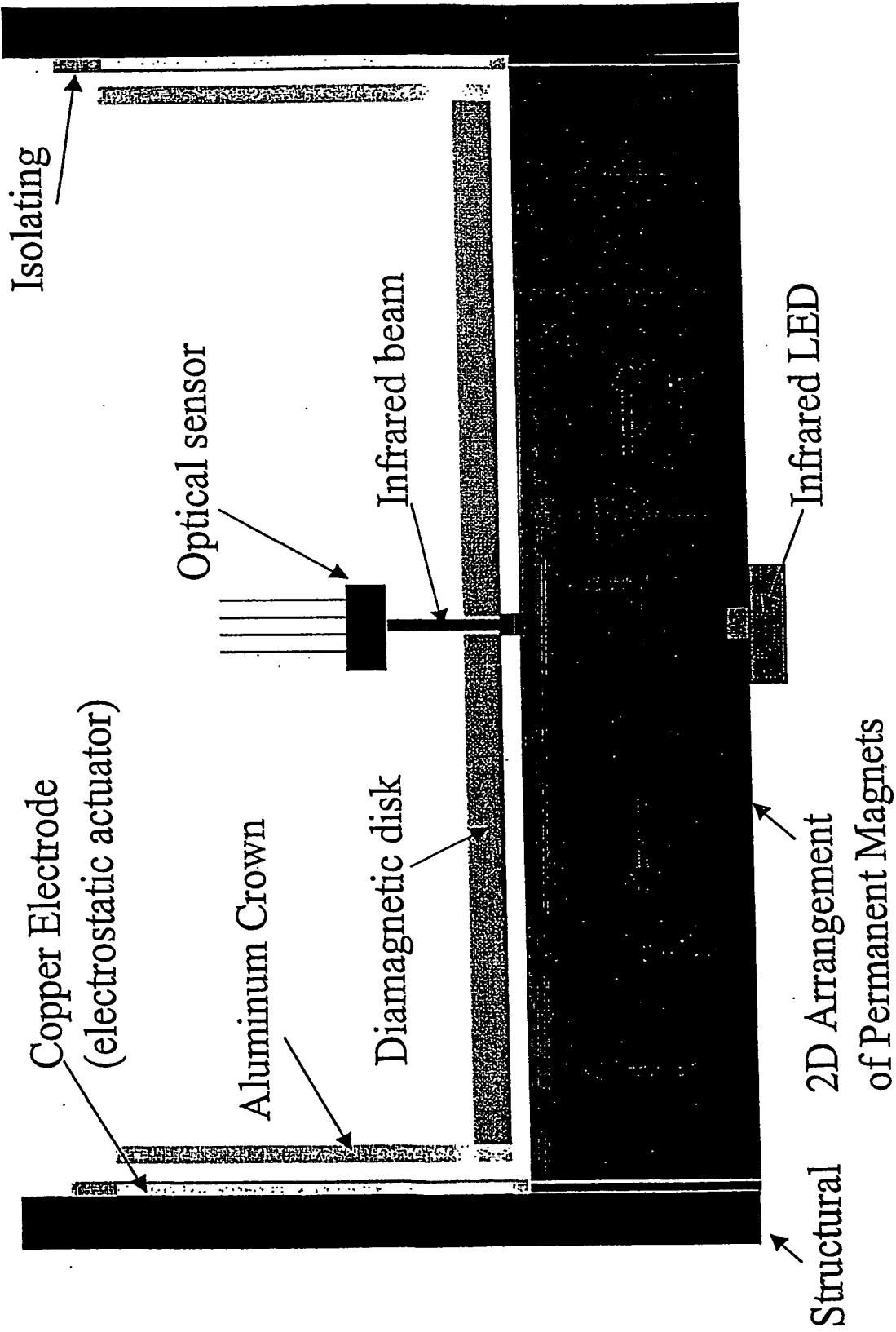The invention relates to two-dimensional permanent magnet arrays for diamagnetic levitation.

Isolating

Copper Electrode
(electrostatic actuator)

Aluminum Crown

Optical sensor

Infrared beam

Diamagnetic disk

Infrared LED

Structural   2D Arrangement
of Permanent Magnets

Figure 1

Position control of the diamagnetic disc

Electrostatic actuators

Optical sensor

controler

Diamagnetic disk

Infrared LED
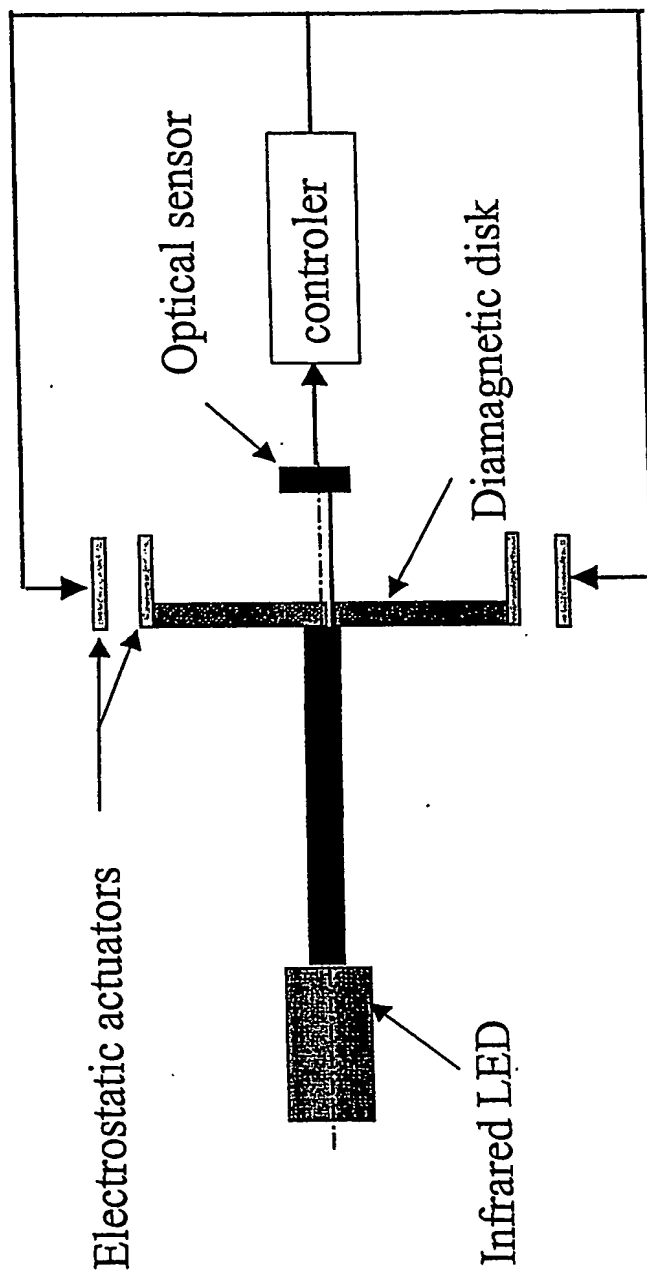
Figure 2

Position Control of the diamagnetic disc in differential mode
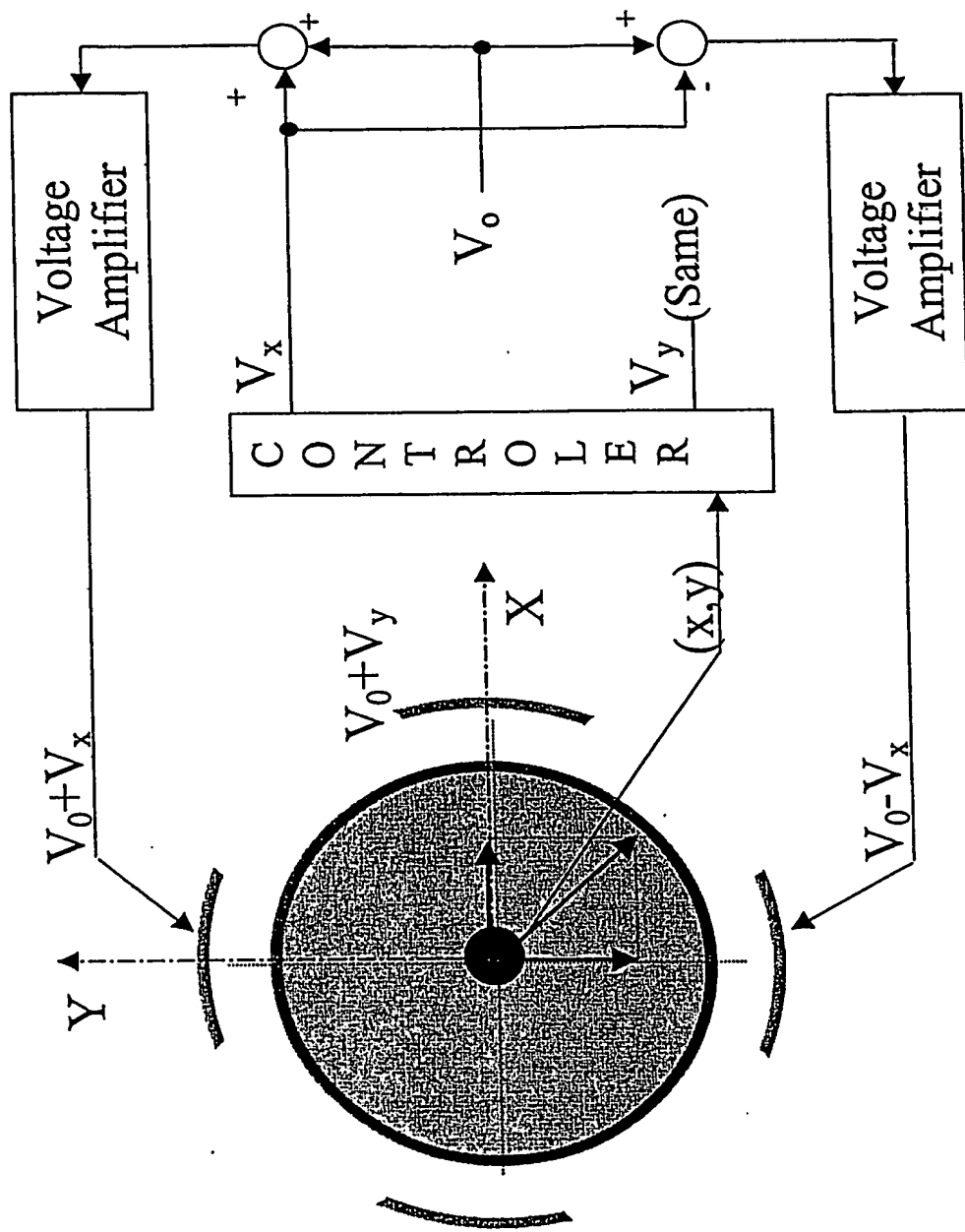
Figure 3

Signal conditioning of the sensor

Currents which are proportionnals to the illuminated surface and to the intensity of the spot

i_A

i_D

X

Infrared Spot

i_C

i_B

Y

D

A

C

B
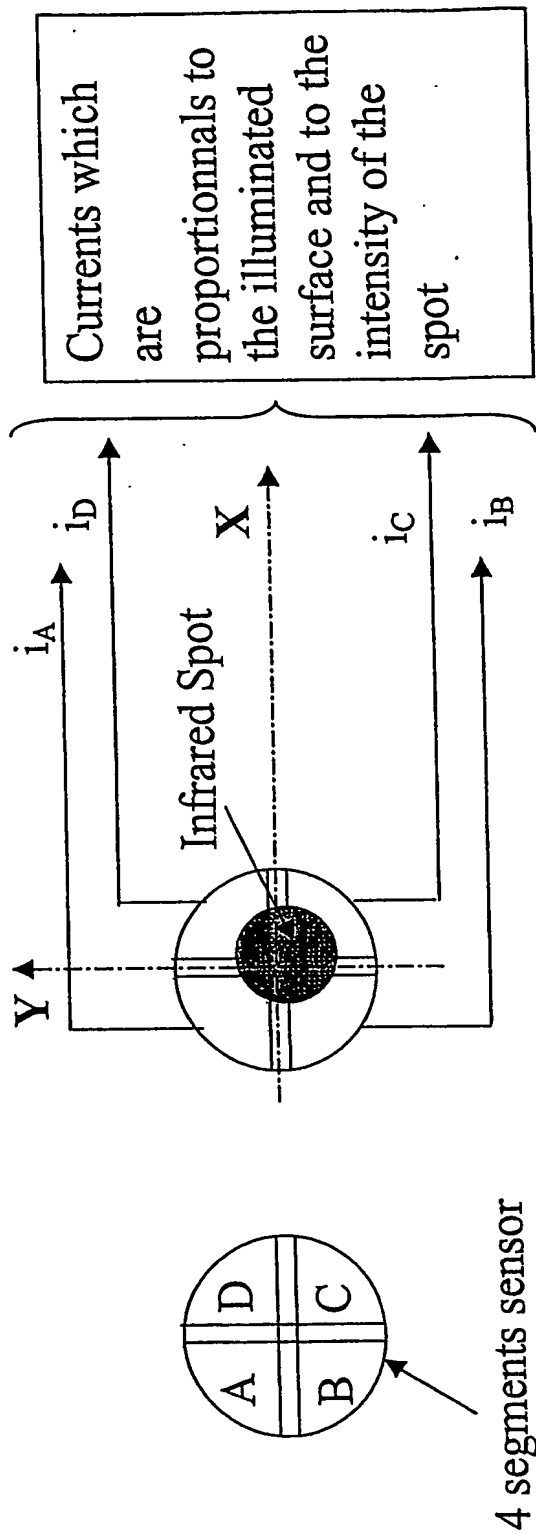
4 segments sensor

$X=(C+D)-(A+B)$
$Y=(A+D)-(B+C)$

Figure 4